Crop Coefficient and Evapotranspiration of Tef at Melkassa, Central Rift Valley of Ethiopia

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Abstract

Rational application of irrigation water is based on the knowledge crop evapotranspiration. The crop evapotranspiration is widely estimated by ETo-Kc approach. Study was undertaken at the experimental farm of Melkassa agricultural research center located in the central rift valley of Ethiopia. Non-weighing lysimeter was used to measure daily ET_c of tef on a clay loam soil. The ET_o was determined from weather data and crop coefficient was obtained from the ratio of measured ETc to estimated ETo. The measured ET_c values were 36.4 mm, 109.9 mm, 166.5 mm, and 50.9 mm during the initial, development, mid-season and late season growth stages, respectively. The K_c-values, were 0.46, 1.03 and 0.57 during the initial, mid-season stages and late season, respectively. The information obtained can be useful in planning, design and operation of irrigation scheme under similar agro-ecological conditions of Melkassa.

Keywords. Crop coefficient, crop evapotranspiration, lysimeter, tef

Introduction

Irrigation water is an input for maximizing crop production and a rational application of irrigation water is based on the knowledge crop evapotranspiration (ETc). Accurate estimation of ETc is essential for proper water resource and irrigation project planning and, irrigation water management practices.

An important element in the estimation of ETc is the reference evapotranspiration (ETo). The ETo is a climatic parameter used to estimate evaporative demand of the atmosphere independent of crop type. Various method were develop to estimate ETo and FAO Penman-Monteith estimation method is the single method accepted worldwide (Allen *et al.*, 1998).

The ETc is widely estimated using ETo-Kc approach. The Kc is a crop coefficient and serves as an aggregation of the physical and physiological differences between crops. The ETc can be determined from isolated crop root zone grown inside a lysimeter. A lysimeters is a tank containing hydrologically isolated soil from surrounding soil and eliminate surface flow and subsurface flow into and out of the lysimeter. The method permits to monitor the incoming and outgoing water flux into and from the crop root zone, respectively over growing periods. (Allen *et al*. 1998).

Tef is one of the most important cereal crops grown in Ethiopia and ranks first in cultivated area among all annual crops and occupies about 29 percent of the land devoted to cereals. The crop is predominantly produced as a staple food for local consumption and an important cash crop for farm households. It is produced solely under rain fed conditions during mid-July to early August, usually when the soil water is assumed to reach near field capacity (Steduto *et al.*, 2012).

Tef is grown at altitudes ranging from 1000 to 2500 masl with a mean temperature ranging from 10°C to 27°C (Seyfu, 1997). The crop is considered to be tolerant to both drought and waterlogging (Mulu *et al.*, 2001. Research shows tef benefits from supplementary irrigation in locations prone to terminal drought (Araya *et al.*, 2010).

Locally determined Kc-values were not available for many crops in Ethiopia and rather the Kc-values from reference books were used. Yenesew (2015) and Solomon (2010) studied the ETc and Kc-values for tef in semi-arid areas values during rainy season. The Kc- values obtained were not consistent and were a one year result. Doorenbos and Pruitt (1977) emphasized the strong need for locally calibrated Kc-values under given climatic conditions. Hence, this study was initiated to determine the seasonal ETc and Kc for tef cultivar Gemechis at different growth stage under climatic condition of Melkassa.

Materials and Methods

Study area

The study was conducted at Melkassa Agricultural Research Center. The center is located in the Central Rift Valley of Ethiopia (8°24 N latitude and 39°21 E longitude with altitude of 1,550 masl). The climate of the area is characterized as semi-arid with low and erratic rainfall pattern. The long-term climatic data (1977 2018) indicate annual average of 825 mm and about 67% of the total rainfall of the area occurs from June to September. The mean maximum and minimum temperatures were 28.7°C and 13.8°C, respectively.

The soil texture in the study area was clay loam with bulk density of 1.11 gm/cm^3. Field capacity (FC) and permanent wilting point (PWP) of the soil were 34.6% and 17.6%, respectively.

Experimental setup

Two non-weighing lysimeters of $2m^2$ (2x1) and $4m^2$ (2x2) area and 1m depth were used for this experiment. Each lysimeter has an access chamber for aeration and underground steel pipes connected to drain chamber for collecting excess water. The rim of each lysimeter protrudes 10 cm above the soil surface to avoid surface water run-on and runoff that may happen during the rain occurrence. Access tubes were installed at the center of each lysimeter down to 100 cm depth to monitor the soil moisture inside the lysimeter.

Tef agronomy

Tef (Gemechis cultivar) was sown in late July on carefully prepared inside and outside the lysimeter to maintain a similar environment. Irrigation water was applied inside and outside the lysimeter at planting to bring the soil moisture to FC and continued irrigation when 50% of the total available water depleted within the root depth. Allen et al. (1998) indicated the allowable depletion fraction for all cereals as 0.55 and pointed out that for hot dry weather conditions, where ETc is high, the depletion fraction is 10-25% less than the value indicated. All other cultural practices other than irrigation for the outside and inside the lysimeters were same recommended for the area. Irrigation was terminated when the crop show sign of maturity and harvested in the late October during the three successive experimental period.

Soil moisture measurement and irrigation application

Soil moisture was measured using calibrated neutron probe for the lower depths (15-30, 30-45, 45-60, 60-75 and 75-90cm) and gravimetric method was used for the upper depth of 0-15cm during the growth period. The amount of irrigation was dependent on the growth stage of the crop, weather, and rooting depth. Measured amount of irrigation was applied to the crop using graduated buckets.

Determination of crop evapotranspiration

The tef ETc for each growth stage was obtained from the following soil water balance equation.

$$ETc = I + R \quad D -$$

where ETc is evapotranspiration of the crop (mm), I is depth irrigation (mm), R is rainfall (mm), D is drainage water (mm), and S is change in storage of soil moisture (mm).

Daily amount of rainfall was obtained from the meteorological observatory located near the experimental plots. Deep percolation was observed daily that may occur from rainfall events in excess above and measured with the help of graduated cylinder at drainage collection chamber.

Determination of reference crop evapotranspiration

Daily metrological data such as minimum and maximum temperatures, sunshine hours, wind speed and relative humidity were collected from Melkassa Agricultural Research Center s meteorological observatory. Daily ET_o computed from FAO Penman-Monteith method using cropwpat 8.0 model (Allen et al. 1998).

The Kc-values for the different growth stages were obtained from the following relationship.

$$Kc = ETc / ETo$$

where *Kc* is crop coefficient (fraction); *ETc* is crop evapotranspiration (mm/day), and *ETo* is reference evapotranspiration (mm/ day).

Results and Discussion

Crop water requirement

The result for the water balance component as obtained from the lysimeter and daily ETo as computed from climatic data is presented Table 1. The crop water requirement of tef was low at the initial stage and increased during the development stage reaching maximum value of 5.04 mm day^{-1} at mid-season stage, and thereafter declined during late-season stage. The difference in ETc is attributed to the combined effects of development of crop, changes in evaporative demand of the atmosphere and difference in energy-absorption characteristics. The increase in ETc during the development stages can be explained by change in evaporative demand and rapid crop growth. The reduction in ETc in the late stage was due to the physiological deterioration of foliage as a result of translocation of photosynthesis from leaves to seeds, which reduced crop transpiration, and the termination of irrigation. Stage-wise crop evapotranspiration of tef over years and three years mean reference evapotranspiration are presented Table 4.

Table 1.1. Water balance components for tef under Melkassa climatic condition during 2015 cropping season

DAS	Irrigation (mm)	Rain (mm)	Drainage(mm)	ETc (mm)	ETc (mm/day)	ETo (mm/day)	Kc
1-3	16.00	11.63	6.54	5.08	1.69	5.46	0.31
4 - 6	-	6.00	10.43	5.55	1.85	5.60	0.33
7 - 9	-	0.00	-	6.56	2.19	6.25	0.35
10 – 13	-	13.20	4.01	8.08	2.02	5.18	0.39
14 – 17	-	0.00	-	8.17	2.04	4.75	0.43
18 – 21	-	1.35	-	12.67	3.17	5.66	0.56
22 - 25	19.35	11.10	1.10	15.49	3.87	5.38	0.72
26-30	11.49	2.40	0.00	22.03	4.41	5.25	0.84
31-39	19.63	43.88	16.84	48.17	5.35	5.58	0.96
40-44	21.19	1.88	-	24.81	4.96	4.91	1.01
45-50	-	20.25	-	31.50	5.25	5.10	1.03
51-57	34.18	13.58	-	31.54	4.73	4.59	1.03
58-64	-	12.60	-	35.74	5.11	5.21	0.98
65-69	41.10	1.88	-	24.82	4.96	5.28	0.94
70-74	22.94	0.00	-	25.85	5.17	5.68	0.91
75-79	25.85	0.00	-	24.07	4.81	5.87	0.82
80-85	24.07	0.00	-	24.00	4.00	5.88	0.68
86-93	24.00	6.15	-	22.69	2.84	6.17	0.46
Total	**259.81**	**145.88**	**38.92**	**376.82**			

Table 2.2. Water balance components for tef under Melkassa climatic condition during 2016 cropping season

DAP	Irrigation (mm)	Rain (mm)	Drainage(mm)	ETc (mm)	ETc (mm/day)	ETo (mm/day)	Kc
01–03	16.2	70.8	63.5	7.3	1.8	4.0	0.46
04-08	-	17.8	9.2	10.1	2.0	3.9	0.52
09-14	-	10.6	-	12.5	2.5	4.4	0.57
15-18	-	9.5	-	16.0	3.2	4.5	0.71
19-22	-	10.6	-	14.6	3.6	4.5	0.81
23-29	-	43.3	3.6	25.9	3.7	3.9	0.94
30-31	-	18.4	9.8	8.6	4.3	4.4	0.97
32-33	-	9.3	-	10.1	5.0	5.0	1.00
34-39	-	39.8	21.3	32.5	5.4	4.8	1.13
40-43	-	19.5	-	19.7	4.9	4.3	1.14
44-45	-	12.2	-	8.5	4.3	3.6	1.17
46-51	22.1	34.0	14.4	30.4	5.1	4.4	1.16
52-60	25.6	20.3	-	45.9	5.1	4.5	1.14
61-64	-	0.0	-	23.0	5.8	5.2	1.11
65-69	34.3	4.5	-	27.0	5.4	5.2	1.03
70-79	35.6	-	-	35.6	3.6	5.3	0.67
80-86	-	-	-	18.4	2.6	5.6	0.47
Total	133.8	320.6	121.7	346.0			

Table 3.3. Water balance components for tef under Melkassa climatic condition during 2017 cropping season

DAP	Irrigation (mm)	Rain (mm)	Drainage(mm)	ETc (mm)	ETc (mm/day)	ETo (mm/day)	Kc
01–04	-	31.1	10.0	7.9	2.0	4.39	0.45
05-08	-	21.5	25.2	8.2	2.1	4.38	0.47
09-12	-	1.6	-	9.5	2.4	4.64	0.51
13-16	-	9.0	-	10.9	2.7	5.07	0.54
17-20	13.50	33.4	24.1	9.3	2.3	4.17	0.56
21-23	-	5.6	2.2	9.6	3.2	4.92	0.65
24-27	-	5.1	-	13.6	3.4	4.37	0.78
28-31	14.74	0.0	-	15.6	3.9	4.65	0.84
32-36	-	11.1	-	21.0	4.2	4.58	0.92
37-41	-	29.2	-	22.0	4.4	4.47	0.98
42-46	-	57.2	25.3	17.2	3.4	3.33	1.03
47-51	-	10.7	7.5	22.0	4.4	4.27	1.03
52-55	14.89	-	25.2	20.4	5.1	4.91	1.04
56-59	20.43	5.3	-	18.4	4.6	4.49	1.03
60-63	-	16.9	-	17.6	4.4	4.31	1.02
64-66	-	3.6	24.1	15.3	5.1	4.94	1.03
67-70	25.58	5.4	2.2	20.4	5.1	5.07	1.01
71-75	15.24	-	-	28.0	5.6	5.66	0.99
76-80	28.01	0.2	-	27.8	5.6	5.84	0.95
81-85	27.61	-	-	22.2	4.4	5.77	0.77
86-90	22.22	-	-	17.4	3.5	6.01	0.58
91-96	-	-	-	12.2	2.0	5.08	0.40
Total	182.22	246.53	84.32	366.58			

*DAS = Days after sowing,

As can be observed from Table 1.1 to 1.3, the crop growth stages of tef under Melkassa climatic condition could take 15, 25, 35 and 15 days during initial, crop development, midseason and late season growth stages, respectively. And hence, the total growth period for tef cultivar Gemechis was 90 days.

Table 4. Stage-wise tef ETc over years and mean ETo under Melkassa climatic condition

Cropping season	Stage-wise ET_c (mm)				
	Initial	Development	Mid-season	Late season	Total growing period
Year – I	33.44	123.18	175.09	46.69	378.40
Year – II	29.92	107.56	154.54	54.03	346.05
Year – III	45.88	98.99	169.86	51.86	366.58
Average ETc ± STDEV	36.41 ±6.85	109.91 ±10.01	166.49 ±8.72	50.86 ±3.08	363.67 ±13.36
ETo (mm)	79.83	124.52	163.37	88.78	456.50
Average Kc	0.46	0.88	1.02	0.57	0.80

Crop coefficient

The computed Kc for tef is presented in Table 4. Crop coefficient curve for average values over year is indicated in Fig. 1. It can be observed that there was a consistent rise from 0.46 to 1.03 and a decrease to 0.57. The midseason stage runs from effective full cover to the start of maturity. The beginning of late season has been indicated by yellowing or senescence of leaves, to the degree that the crop evapotranspiration is reduced relative to the reference ETo. Senescence is usually associated with less efficient stomata conductance of leaf surfaces due to the effects of ageing, thereby restricting transpiration and causing a reduction in crop coefficient. Factors affecting the value of the crop coefficient (K_c) are mainly the crop characteristics, crop planting or sowing date, rate of crop development, length of growing season, soil evaporation and climate (Doorenbos and Pruitt 1977).

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Table 4. Stage-wise crop coefficient values for tef under Melkassa climatic condition

Lysimeter	Stage-wise crop coefficient (K_c)		
	Initial	Mid-season	End of season
Year – 1	0.36	0.95	0.57
Year – 2	0.52	1.13	0.57
Year – 3	0.51	1.01	0.58
Average Kc	0.46	1.03	0.57

Crop coefficient and days after sowing (DAS)

Regression analysis can be used to express the relationship between Kc values and day after sowing, DAS (Yenesew 2015; Hanson and May 2006; Kang et al., 2003). A multiple regression analysis with fifth-order polynomial equation was developed gave coefficient of determination as $r^2 = 0.92$.

$$Kc = -2E\text{-}09DAS^5 + 5E\text{-}07DAS^4 - 5E\text{-}05DAS^3 + 0.0022DAS^2 - 0.0165DAS + 0.4293$$
$$R^2 = 0.92$$

Kang *et al.* (2003) proposed a fifth order polynomial equation for wheat and maize with a high coefficient of determination (r^2) of 0.96. Bossie (2009). Therefore, this equation is helpful in predicting Kc values for irrigation scheduling.

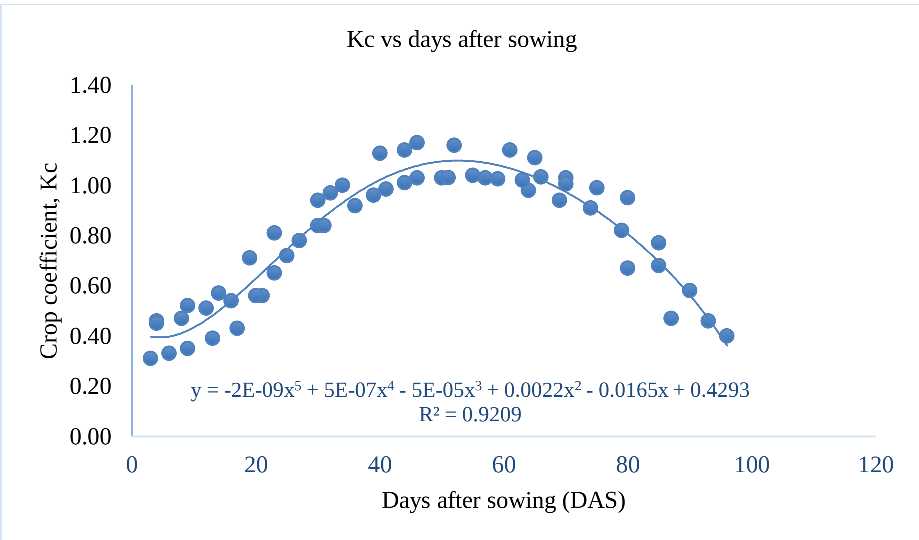

Figure 1. Observed crop coefficient values for tef

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